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(54) SECONDARY CELL INSPECTION METHOD AND SECONDARY CELL INSPECTION DEVICE

VERFAHREN UND VORRICHTUNG ZUR SEKUNDÄRZELLENINSPEKTION

PROCÉDÉ ET DISPOSITIF D’INSPECTION D’ÉLÉMENT SECONDAIRE

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(56) References cited:
WO-A1-2017/002953
WO-A1-2019/187264
GB-A- 2 532 726
JP-B1- 6 842 212
US-A1- 2011 060 538
US-A1- 2014 372 054
US-A1- 2014 372 054

Description

Technical Field

[0001] The present invention relates to a technique for inspecting a secondary battery such as a lithium-ion battery.

Background Art

[0002] As a method of inspecting the internal state of a secondary battery, an AC impedance analysis method based on a frequency response analysis (FRA) method is well known, and a method of applying an equivalent circuit model to decompose the secondary battery into time-constant elements in order to interpret various internal reactions of the secondary battery is established.

[0003] Patent Literature 2 discloses an internal impedance diagnostic system for estimating cell impedance parameters from an impedance equivalent circuit model including the application or detection of a time-varying current signal through a cell, measurement of voltage and current variations, application of an adaptive filter on the sampled data to identify the m-order transfer function for the measured system, constructing a set of simultaneous equations, extracting individual impedance parameter values from the equations, running diagnostic tests and algorithms to analyze the change in cell impedance values and computing accurate cell related estimation parameters and conditions.

Citation List

Patent Literature

[0004]

Patent Literature 1: Japanese Patent No. 5924617
Patent Literature 2: GB 2 532 726 A

Summary of Invention

Technical Problem

[0005] However, multipoint measurements from a high frequency range of about 10 kHz up to a low frequency range of about 10 mHz to 100 mHz are required for the AC impedance analysis. Therefore, the inspection of the secondary battery takes a long time. Further, since a dedicated measuring device is required, it is difficult to put the method into practical use in such a scene that a short takt time is prerequisite such as a mass production line. Although an inspection machine having a certain degree of accuracy in a short time is required upon mass production shipment inspection of secondary batteries and product acceptance inspection, since the characteristics of each battery is changing depending on the operating state of the battery (such as voltage (SOC), operating current, and battery temperature), inspection must be performed by setting constant conditions. Therefore, an inspection device with good reproducibility is desired. Although pass/fail determination criteria are set from a statistical population distribution in the mass production line or the like, such settings are possible only when the inspection conditions are fixed, and there were hardly any methods of being able to determine pass/fail of a secondary battery on the market.

[0006] Therefore, the object of the present invention is to provide a secondary battery inspection device or the like capable of improving inspection accuracy while simplifying the inspection of a secondary battery.

Solution to Problem

[0007] The secondary battery inspection device and the secondary battery inspection method according to the present invention are defined in the appended claims.

Brief Description of Drawings

[0008]

FIG. 1 is an explanatory diagram related to the configuration of a secondary battery inspection device as one embodiment of the present invention.
FIG. 2A is a first illustrated diagram of an equivalent circuit of the internal resistance of a secondary battery.

FIG. 2B is a second illustrated diagram of the equivalent circuit of the internal resistance of the secondary battery.
FIG. 2C is a third illustrated diagram of the equivalent circuit of the internal resistance of the secondary battery.
FIG. 2D is a fourth illustrated diagram of the equivalent circuit of the internal resistance of the secondary battery.
FIG. 3A is a diagram representing a transfer function of a connection resistance component R_0 of the secondary battery.
FIG. 3B is a diagram representing an IIR transfer function of the i-th RC parallel circuit composed of a charge transfer resistance R_i and a capacitor C_i.
FIG. 3C is a diagram representing an IIR transfer function of an inductance component L.
FIG. 3D is a diagram representing an FIR transfer function of a Warburg impedance W_0.
FIG. 4 is an explanatory chart related to Nyquist plots of the secondary battery.
FIG. 5A is an explanatory chart related to a first evaluation index according to a first sampling period.
FIG. 5B is an explanatory chart related to a second evaluation index according to the first sampling period.
FIG. 5C is an explanatory chart related to a third evaluation index according to a second sampling period.

Description of Embodiment

(Configuration of Secondary Battery Inspection Device)

[0009] A secondary battery inspection device 100 as one embodiment of the present invention illustrated in FIG. 1 is composed of a processor (arithmetic processing unit), a memory (storage device), an I/O circuit, and the like. In the memory or a storage device separate from this memory, a program (software) is stored and held in addition to various data such as parameters for defining a secondary battery model. For example, each of plural identifiers for identifying a secondary battery or the type of a target machine element (identified by the standard and specifications) in which this secondary battery is installed, and each of plural secondary battery models are stored and held in the memory in association with each other. The processor reads necessary program and data from the memory, and executes arithmetic processing according to the program based on the data to execute arithmetic processing or a task to be described later.
[0010] The secondary battery inspection device 100 includes an OCV detection element 102, a subtraction element 104, a temperature compensation element 110, a first sampling period output element 111, a first model parameter setting element 112, a first voltage estimation element 114, a first division element 116, a second sampling period output element 121, a second model parameter setting element 122, a second voltage estimation element 124, a second division element 126, a first evaluation element 142, a second evaluation element 144, and a third evaluation element 146.

(Secondary Battery Model)

[0011] Each of the secondary battery models is a model representing voltage V(t) output from a secondary battery 200 when current I(t) is input to the secondary battery 200. The voltage V(t) is defined by equation (01) using an open circuit voltage OCV of the secondary battery 200 and a transfer function H(t) of the internal resistance.

$$V(t) = OCV + H(t)\cdot I(t) \; ...(01)$$

[0012] The transfer function H(t) of an equivalent circuit model of the internal resistance of the secondary battery is defined by equation (02).
[Math. 1]

$$H(t) = H_0(t) + \sum_{i=1}^{m} H_i(t) + H_W(t) + H_L(t) \; ...(02)$$

[0013] "$H_0(t)$," "$H_i(t)$," "$H_W(t)$," and "$H_L(t)$" are defined by parameters representing the characteristics of the internal resistance of the secondary battery.
[0014] In FIG. 2A, an example of an equivalent circuit of the internal resistance of the secondary battery 200 is illustrated. In this example, the equivalent circuit of the internal resistance is defined by a series circuit of a connection resistance component R_0, the i-th RC parallel circuit (i = 1, 2, ..., m) composed of charge transfer resistances R_i and capacitors C_i, a Warburg impedance W_0, and a coil L. In FIG. 2A, the number, m, of RC parallel circuits connected in series is "4." As illustrated in FIG. 2B, the number, m, of RC parallel circuits connected in series may be smaller than 4, or may be larger than 4. As illustrated in FIG. 2C and FIG. 2D, respectively, the Warburg impedance W_0 may also be connected in series with a resistance R in at least any one of RC parallel circuits (for example, in the first RC parallel circuit). Further, each capacitor C may be replaced with a CPE (Constant Phase Element). In addition, the coil L may be omitted.
[0015] The transfer function $H_0(z)$ of the resistance R_0 is defined by equation (10). In FIG. 3A, a block diagram

representing the transfer function $H_0(z)$ of the resistance R_0 is illustrated.

$$H_0(z) = R_0 \ ...(10)$$

[0016] The dependency of R_0 on temperature θ is predetermined according to the equation (10) based on the measurement results of Nyquist plots of a reference secondary battery at different temperatures θ (see FIG. 4), respectively. In other words, the coefficient R_0 is defined as a dependent variable or a function when the temperature θ for defining the transfer function $H_0(z)$ of the resistance R_0 is taken as the main variable.

[0017] The transfer function $H_i(z)$ of the i-th RC parallel circuit is defined by equation (20) as an IIR (Infinite Impulse Response) system. In FIG. 3B, a block diagram representing the transfer function $H_i(z)$ of the i-th RC parallel circuit is illustrated.

$$H_i(z) = (b_0 + b_i z^{-1})/(1 + a_i z^{-1}) \ ...(20)$$

[0018] A transfer function $H_i(s)$ of the i-th RC parallel circuit in an s region is expressed by equation (21).

$$H_i(s) = R_i/(1 + \tau_i s) \text{ (where } \tau_i = 1/R_iC_i) \ ...(21)$$

[0019] When the transfer function $H_i(s)$ is bilinear-transformed ($s \rightarrow (2/T)(1-z^{-1})/(1 + z^{-1})$ (where T is a sampling period)), the transfer function $H_i(z)$ of the i-th RC parallel circuit in a z region is expressed by equation (22).

$$H_i(z) = \{R_i/(1 + 2\tau_i/T) + R_i/(1 + 2\tau_i/T)z^{-1}\} /\{1+(1 - 2\tau_i/T)/(1 + 2\tau_i/T)z^{-1}\} \quad (22)$$

[0020] From a comparison between the equations (20) and (22), each of coefficients b_0, b_i, and a_i in the IIR transfer function is defined by each of equations (221) to (223), respectively.

$$b_0 = R_i/(1 + 2\tau_i/T) \ ...(221)$$

$$b_i = R_i/(1 + 2\tau_i/T) \ ...(222)$$

$$a_i = -\{1+(1 - 2\tau_i/T)/(1 + 2\tau_i/T)\} \ ..(223)$$

[0021] The dependencies of R_i and C_i on temperature θ are predetermined according to the equation (21) based on the measurement results of Nyquist plots of the secondary battery at different temperatures θ (see FIG. 4), respectively. In other words, each of the coefficients b_0, b_i, and a_i that define the transfer function $H_i(z)$ of the i-th RC parallel circuit is defined as a dependent variable or a multivariable function when the temperature θ and sampling frequency T are taken as main variables.

[0022] The transfer function $H_L(z)$ of the coil L is defined by equation (30) as the transfer function of the IIR system. In FIG. 3C, a block diagram representing the transfer function $H_L(z)$ of the coil L is illustrated.

$$H_L(z) = (2L_0/T)(1 - z^{-1})/(1 + z^{-1}) \ ...(30)$$

[0023] A transfer function $H_L(s)$ of the coil L in the s region is expressed by equation (31).

$$H_L(s) = sL_0 \ ...(31)$$

[0024] When the transfer function $H_L(s)$ is bilinear-transformed, the transfer function $H_L(z)$ of the coil L in the z region is represented by equation (32).

$$H_L(z) = \{2L_0/T - 2L_0/Tz^{-1}\}/(1 + z^{-1}) \ ...(32)$$

[0025] From a comparison between the equations (30) and (32), each of the coefficients b_0, b_i, and a_i in the IIR transfer function is defined by each of equations (321) to (323), respectively.

$$b_0 = 2L_0/T \ldots(321)$$

$$b_i = -2L_0/T \ldots(322)$$

$$a_i = -1 \ldots(323)$$

[0026] The dependence of L_0 on temperature θ is predetermined according to the equation (31) based on the measurement results of Nyquist plots of the reference secondary battery at each of different temperatures θ (see FIG. 4), respectively. In other words, each of the coefficients b_0 and b_i that define the transfer function $H_i(z)$ of the coil L is defined as a dependent variable or a multivariable function when the temperature θ and sampling frequency T are taken as main variables.

[0027] The transfer function $H_W(z)$ of the Warburg impedance W_0 is defined by equation (40) as a transfer function of a FIR (Finite Impulse Response) system. In FIG. 3D, a block diagram representing the transfer function $H_W(z)$ of the Warburg impedance W_0 is illustrated.

[Math. 2]

$$H_W(z) = \sum_{k=0}^{n} h_k z^{-k} \ldots(40)$$

[0028] A transfer function $H_W(s)$ of the Warburg impedance W_0 in the s region is represented by equation (41).

$$H_W(s) = R_W \tanh(sT_W)^p/(sT_W)^p \ldots(41)$$

[0029] When the transfer function $H_L(s)$ is bilinear-transformed, the transfer function $H_W(z)$ of the Warburg impedance W_0 in the z region is represented by equation (42).

$$H_W(z) = R_W \tanh[(2T_W/T)(1 - z^{-1})/(1 + z^{-1})]^p$$

$$/\{(2T_W/T)(1 - z^{-1})/(1 + z^{-1})\}^p \ldots(42)$$

[0030] Thus, from a comparison between the equations (40) and (42), it is found to be difficult to determine each of the coefficient h_k in the FIR transfer function, respectively. Therefore, the dependencies of R_W, T_W, and p on temperature θ are determined according to the equation (41) based on the measurement results of Nyquist plots of the reference secondary battery at each of different temperatures θ (see FIG. 4), respectively. Then, the equation (42) is subjected to inverse-FFT transform to be extracted as the coefficients of delay elements z_k (k = 0 to n, where n is, for example, about several tens to 1000) in order to approximately define the transfer function $H_W(z)$ of the Warburg impedance W_0 as an FIR transfer function as in equation (40). This is derived from the fact that the influence of the Warburg impedance W_0 is reflected on a low frequency side in the Nyquist plots. In other words, each of the coefficients h_k that define the transfer function $H_W(z)$ of the Warburg impedance W_0 is defined as a dependent variable or a multivariable function when the temperature θ and sampling frequency T are taken as main variables.

[0031] In FIG. 4, an example of Nyquist plots representing the measurement results of a complex impedance Z of the secondary battery 200 is illustrated together with an approximate curve of the plots. The horizontal axis is the real part ReZ of the complex impedance Z, and the vertical axis is the imaginary part -ImZ of the complex impedance Z. In a region of -ImZ > 0, lower frequency complex impedance Z is represented as ReZ increases.

[0032] A value of ReZ when -ImZ = 0 (FIG. 4 (first evaluation section)) corresponds to the connection resistance component R_0 of the secondary battery 200 (see FIG. 3A). A section in a region of -ImZ < 0 (first evaluation section) surrounded by the dot-and-dash line in FIG. 4 corresponds to the impedance of wiring inductance L_0 of the electrodes and the like of the secondary battery 200 (see FIG. 3B). A crushed semicircular shaped section in a region of -ImZ > 0 (second evaluation section) surrounded by the long dashed double-dotted line in FIG. 4 corresponds to reaction resistance and electric double layer (impedance of the first to the m-th RC parallel circuits) at the electrode interface of the secondary battery 200 (see FIG. 3C). The radius tends to be smaller as the temperature T of the secondary battery 200 increases. The influence of the Warburg impedance W_0 of the secondary battery 200 is reflected in an approximately linear section standing up at about 45° in a low frequency range in a region of ImZ > 0 (third evaluation section) surrounded by the dashed line in FIG. 4 (see FIG. 3D).

[0033] The approximate curve of the complex impedance Z of the secondary battery, which is represented by solid

Nyquist plots in FIG. 4 is determined under the assumption that the transfer function H(t) of the equivalent circuit model of the internal resistance of the secondary battery is defined according to the equation (02). Thus, values of parameters R_0 (see the equation (10)), R_i and C_i (see the equation (21)), L_0 (see the equation (31)), R_W, T_W, and p (see the equation (41)) are determined at each temperature θ. The value of the open circuit voltage OCV in each secondary battery model is identified by the measured value of the open circuit voltage OCV (see the equation (01)). Then, secondary battery models are established by the parameter values for various types of secondary batteries 200.

(Secondary Battery Inspection Method)

[0034] An inspection method of the secondary battery 200 executed by the secondary battery inspection device 100 having the configuration mentioned above will be described.

[0035] The impulse current I(t), the voltage V(t), and the temperature $\theta(t)$ of the secondary battery 200 are measured by a current sensor S1, a voltage sensor S2, and a temperature sensor S0, respectively, when the impulse current I(t) is applied by a charge/discharge device 300 to the secondary battery 200 to be inspected.

the measurement result of the temperature $\theta(t)$ of the secondary battery 200 is input to the temperature compensation element 110, and a temperature compensation model parameter according to the measurement result is output from the temperature compensation element 110. Specifically, values $R_0(\theta)$, $R_i(\theta)$, $C_i(\theta)$, $L_0(\theta)$, $R_W(\theta)$, $T_W(\theta)$, and $p(\theta)$ of the parameters R_0 (see the equation (10)), R_i and C_i (see the equation (21)), L_0 (see the equation (31)), and R_W and T_W (see the equation (41)) according to the temperature θ are determined. These model parameters can be determined as average values of a good product population from mass-produced products of secondary batteries, and used as a reference model for pass/fail determination.

[0036] The temperature compensation model parameter is input from the temperature compensation element 110 to the first model parameter setting element 112, and the IIR model parameters $b_0(\theta, T_1)$, $b_i(\theta, T_1)$, and $a_i(\theta, T_1)$ are determined by the first model parameter setting element 112 based on the temperature compensation model parameters $R_i(\theta)$ and $C_i(\theta)$ according to the first sampling period T_1 (see the equations (221) to (223)). The IIR model parameters $b_0(\theta, T_1)$, $b_i(\theta, T_1)$, and $a_i(\theta, T_1)$ are determined by the first model parameter setting element 112 based on the temperature compensation model parameter $L_0(\theta)$ according to the first sampling period T_1 (see the equations (321) to (323)). The FIR model parameter $h_k(\theta, T_1)$ is determined by the first model parameter setting element 112 based on the temperature compensation model parameters $R_W(\theta, T_1)$, $T_W(\theta, T_1)$, and $p(\theta, T_1)$ according to the first sampling period T_1 (see the equation (40)).

[0037] The voltage V(t) of the secondary battery 200 is inferred by the first voltage estimation element 114 based on the measurement result of the impulse current I(t) of the secondary battery 200 according to the secondary battery model defined by the transfer function H(t) according to the first sampling period T_1 as a short period (for example, about 10 ms) (see the equation (01)). In FIG. 5A and FIG. 5B, the measured values of the voltage V of the secondary battery 200 at the time of discharge are illustrated by the dotted line, approximate curves representing the measured values of the OCV of the secondary battery 200 in each first sampling period T_1 are illustrated by the dashed line, and approximate curves representing the estimation results of the voltage V(t) of the secondary battery 200 in each first sampling period T_1 by the first voltage estimation element 114 are illustrated by the solid line, respectively. Since the open circuit voltage OCV is not considered in the secondary battery model, the estimation results D of the voltage V(t) of the secondary battery 200 in each first sampling period T_1 by the first voltage estimation element 114 is inferred based on the OCV (see FIG. 5A, FIG. 5B/down arrow D).

[0038] The temperature compensation model parameter is input from the temperature compensation element 110 to the second model parameter setting element 122, and the IIR model parameters $b_0(\theta, T_2)$, $b_i(\theta, T_2)$, and $a_i(\theta, T_2)$ are determined by the second model parameter setting element 122 based on the temperature compensation model parameters $R_i(\theta)$ and $C_i(\theta)$ according to the second sampling period T_2 (see the equations (221) to (223)). The IIR model parameters $b_0(\theta, T_2)$, $b_i(\theta, T_2)$, and $a_i(\theta, T_2)$ are determined by the second model parameter setting element 122 based on the temperature compensation model parameter $L_0(\theta)$ according to the second sampling period T_2 (see the equations (321) to (323)). The FIR model parameter $h_k(\theta, T_2)$ is determined by the second model parameter setting element 122 based on the temperature compensation model parameters $R_W(\theta, T_2)$, $T_W(\theta, T_2)$, and $p(\theta, T_2)$ according to the second sampling period T_2 (see the equation (40)).

[0039] The voltage V(t) of the secondary battery 200 is inferred by the second voltage estimation element 124 based on the measurement result of the impulse current I(t) of the secondary battery 200 according to the secondary battery model defined by the transfer function H(t) according to the second sampling period T_2 as a long period (for example, about 1 s) (see the equation (01)). In FIG. 5C, the measured values of the voltage V of the secondary battery 200 at the time of discharge are illustrated by the solid line, an approximate curve representing the measured values of the OCV of the secondary battery 200 in each second sampling period T_2 is illustrated by the dashed line, and an approximate curve representing the estimation result of the voltage V(t) of the secondary battery 200 in each second sampling period T_2 by the second voltage estimation element 124 is illustrated by the solid line. Since the open circuit voltage OCV is not considered in the secondary battery model, the estimation result E of the voltage V(t) of the secondary battery 200 by the second voltage estimation element 124 is inferred based on the OCV (see FIG. 5C/down arrow E).

[0040] The voltage V(t) of the secondary battery 200 is input to the secondary battery inspection device 100, and the open circuit voltage OCV(t) of the secondary battery 200 is detected by the OCV detection element 102 based on input A concerned. Then, a difference C = A - B of input A = V(t) and output B = OCV(t) of the OCV detection element 102 is output by the subtraction element 104. The difference C is illustrated by the down arrow C in each of FIG. 5A, FIG. 5B, and FIG. 5C, which represents a difference between the measured value (solid line) of the voltage V of the secondary battery 200 at the time of discharge and the measured value dotted line) of the OCV.

[0041] The difference C is input from the subtraction element 104 to the division element 116, and the estimation result D of the voltage V(t) of the secondary battery 200 is input from the first voltage estimation element 114 to calculate a ratio C/D of both inputs.

[0042] C/D at each point of time in a first period (see FIG. 5A/region surrounded by the dashed box) immediately after the impulse current I(t) starts flowing from the division element 116 is input to the first evaluation element 142, and the connection resistance component R_0 and the inductance element L_0 of the secondary battery 200 in the first evaluation section is evaluated by the first evaluation element 142 based on a statistical index value, such as an average value of the input, a variance value, a deviation value, or an intermediate value of the maximum value and the minimum value. Here, since contribution by L_0 is only the impedance on the imaginary axis and there is no contribution as the resistance value, the component to be evaluated is only R_0 after all. The closer C/D to 1, the smaller the change in the connection resistance component R_0 of the secondary battery 200 is evaluated compared with the initial state or the good product population.

[0043] C/D at each point of time in a second period (see FIG. 5B/region surrounded by the dashed box) longer than the first period and starting at the elapse of the first period after the impulse current I(t) starts flowing from the division element 116 is input to the second evaluation element 144, and the reaction resistance and electric double layer (impedance of the first to the m-th RC parallel circuits) at the electrode interface of the secondary battery 200 in the second evaluation section are evaluated by the second evaluation element 144 based on the statistical index value of the input. The closer the C/D to 1, the smaller the change in the reaction resistance and electric double layer (impedance of the first to the m-th RC parallel circuits) at the electrode interface of the secondary battery 200 is evaluated compared with the initial state or the good product population. A tolerance level can be set to the calculated value of C/D for pass/fail determination.

[0044] The difference C is input from the subtraction element 104 to the division element 126, and the estimation result E of the voltage V(t) of the secondary battery 200 is input from the second voltage estimation element 124 to calculate a ratio of C/E of both inputs.

[0045] C/E at each point of time in a third period (see FIG. 5C/region surrounded by the dashed box) longer than the second period and starting at the elapse of the first period after the impulse current I(t) starts flowing from the division element 126 is input to the third evaluation element 146, and the Warburg impedance W_0 of the secondary battery 200 in the third evaluation section is evaluated by the third evaluation element 146 based on the statistical index value of the input. The closer C/E to 1, the smaller the change in the Warburg impedance W_0 of the secondary battery 200 is evaluated compared with the initial state or the good product population. A tolerance level can be set to the calculated value of C/E for pass/fail determination..

[0046] The evaluation results of the first evaluation element 142, the second evaluation element 144, and the third evaluation element 146 are output to an output interface wired or wirelessly connected to the secondary battery inspection device 100.

[0047] Each of the first evaluation element 142, the second evaluation element 144, and the third evaluation element 146 can make the determination with one measurement to estimate which component of the secondary battery is the cause of a failure depending on the combination of the determination results.

Advantageous Effects of Invention

[0048] According to the secondary battery inspection device 100 of the present invention and the secondary battery inspection method executed thereby, for example, as illustrated in Table 1, when the determination result of C/D related to the first evaluation section has a relation to a first determination reference value $\gamma 1$ as expressed in equation (51), it is evaluated to be "OK (the resistance value of the cell constituent material is within a reference range)," while when the determination result of C/D does not have the relation expressed in the equation (51), it is evaluated to be "NG (the resistance value of the cell constituent material exceeds the reference)."

$$1-\gamma 1 < C/D < 1+\gamma 1 \quad ...(51)$$

[0049] Further, as illustrated in Table 1, when the determination result of C/D related to the second evaluation section has a relation to a second determination reference value $\gamma 2$ as expressed in equation (52), it is evaluated to be "OK (there is no abnormality in reactivity between the positive electrode and the negative electrode)," while when the determination result of C/D does not have the relation expressed in the equation (52), it is evaluated to be "NG (there is abnormality in reactivity between the positive electrode and the negative electrode)."

$$1-\gamma 2 < C/D < 1+\gamma 2 \ldots(52)$$

[0050] Further, as illustrated in Table 1, when the determination result of C/E related to the third evaluation section has a relation to a third determination reference value $\gamma 3$ as expressed in equation (53), it is evaluated to be "OK (there is no shortage of electrolyte, no deterioration of the electrolyte, or the like)," while when the determination result of C/E does not have the relation expressed in the equation (53), it is evaluated to be "NG (there is a shortage of electrolyte, a deterioration of the electrolyte, or the like)."

$$1-\gamma 3 < C/D < 1+\gamma 3 \ldots(53)$$

[0051] Thus, according to the present invention, not only can the pass/fail determination of the secondary battery be simply made but also it can be estimated which of components of the secondary battery causes a problem by one measurement.

[0052] The evaluation results may be transmitted from the secondary battery inspection device 100 to a client such as a smartphone, a tablet terminal, or a personal computer, and output to and displayed on an output interface (display) that constitutes part of the client. Thus, since a defect factor can also be estimated while facilitating the inspection of the secondary battery 200, not only can the inspection accuracy be improved, but also a user of the client who engages in the production process can get smooth feedback.

[Table 1]

Individual Abnormality Content	Determination Result in First Evaluation Section	Determination Result in Second Evaluation Section	Determination Result in Third Evaluation Section	Assumed Factor
	Determination Reference $\gamma 1$	Determination Reference $\gamma 2$	Determination Reference $\gamma 3$	
Abnormality of Ro	NG	NG	NG	Increased Resistance of Cell Constituent Material (Contact Failure or Electrical Resistance)
Abnormality of Rn, Cn	OK	NG	NG	Abnormality in Reactivity of Positive Electrode and Negative Electrode
Abnormality of WO	OK	OK	NG	Ion Diffusion Reaction in Electrode, Such as Shortage or Deterioration of Electrolyte

Description of Reference Numerals

[0053] 100...secondary battery inspection device, 102...OCV detection element (voltage recognition element), 104... subtraction element, 110... temperature compensation element, 112...first model parameter setting element, 114...first voltage estimation element, 122...second model parameter setting element, 124...second voltage estimation element, 200...secondary battery, 300...charge/discharge device.

Claims

1. A secondary battery inspection device comprising:

a voltage recognition element configured to recognize a measurement result of voltage of a secondary battery when an impulse current flows into the secondary battery;
a model parameter setting element configured to identify, based on a sampling period, a value of a model

parameter of a secondary battery model in which impedance of internal resistance of the secondary battery is expressed by transfer functions respectively representing an IIR system and an FIR system;
a voltage estimation element which, when the impulse current is input to a specified model as the secondary battery model the value of the model parameter of which is identified by the model parameter setting element, is configured to estimate a model output voltage as a voltage change form output from the specified model; and
an evaluation element which is configured to evaluate based on a ratio (C/D) which is a ratio of a difference (C) between a measured value of the voltage of the secondary battery recognized by the voltage recognition element with respect to an estimation result (D) estimated by the voltage estimation element in each first sampling period as a short period, whether or not a resistance value of a cell constituent material of the secondary battery according to the first sampling period is within a reference range, whether or not a reactivity of a positive electrode or a negative electrode is abnormal, and to evaluate, based on a ratio (C/E) which is a ratio of the difference (C) between the measured value of the voltage of the secondary battery recognized by the voltage recognition element with respect to an estimation result (E) estimated by the voltage estimation element in each second sampling period as a long period, whether or not there is a shortage or a deterioration of an electrolytic solution of the secondary battery according to the second sampling period.

2. The secondary battery inspection device according to claim 1, wherein

the model parameter setting element individually identifies the value of the model parameter based on each of a plurality of sampling periods, respectively,
the voltage estimation element estimates a plurality of model output voltages as voltage change forms respectively output from a plurality of specified models when the impulse current is input to the plurality of specified models as individual secondary battery models with the values of the model parameter identified by the model parameter setting element, and
the evaluation element evaluates a plurality of performances of the secondary battery respectively according to respective of the plurality of sampling periods based on the measurement result of the voltage of the secondary battery recognized by the voltage recognition element, and respective of the plurality of specified model output voltages estimated by the voltage estimation element.

3. The secondary battery inspection device according to claim 1 or 2, further comprising

a temperature compensation element which recognizes a measurement result of temperature of the secondary battery,
wherein the model parameter setting element corrects the value of the model parameter based on the measurement result of the temperature of the secondary battery recognized by the temperature compensation element.

4. A secondary battery inspection method comprising:

a voltage recognition process of recognizing a measurement result of voltage of a secondary battery when an impulse current flows into the secondary battery;
a model parameter setting process of identifying, based on a sampling period, a value of a model parameter of a secondary battery model in which impedance of internal resistance of the secondary battery is expressed by transfer functions respectively representing an IIR system and an FIR system;
a voltage estimation process in which, when the impulse current is input to a specified model as the secondary battery model the value of the model parameter of which is identified in the model parameter setting process, a model output voltage as a voltage change form output from the specified model is estimated; and
an evaluation process of evaluating, based on a ratio (C/D) which is a ratio of a difference (C) between a measured value of the voltage of the secondary battery recognized by the voltage recognition element with respect to an estimation result (D) estimated by the voltage estimation element in each first sampling period as a short period whether or not a resistance value of a cell constituent material of the secondary battery according to the first sampling period is within a reference range, whether or not a reactivity of a positive electrode or a negative electrode is abnormal, and to evaluate, based on a ratio (C/E) which is a ratio of the difference (C) between the measured value of the voltage of the secondary battery recognized by the voltage recognition element with respect to an estimation result (E) estimated by the voltage estimation element in each second sampling period as a long period, whether or not there is a shortage or a deterioration of an electrolytic solution of the secondary battery according to the second sampling period.

Patentansprüche

1. Vorrichtung zur Überprüfung von Sekundärbatterien, umfassend:

   ein Spannungserkennungselement, das konfiguriert ist, ein Messergebnis der Spannung einer Sekundärbatterie, wenn ein Impulsstrom in die Sekundärbatterie fließt, zu erkennen,
   ein Modellparameter-Einstellelement, das konfiguriert ist, basierend auf einem Probenahmezeitraum einen Wert eines Modellparameters eines Sekundärbatteriemodells, in dem die Impedanz des Innenwiderstands der Sekundärbatterie durch Übertragungsfunktionen ausgedrückt wird, die jeweils ein IIR-System und ein FIR-System darstellen, zu identifizieren,
   ein Spannungseinschätzungselement, das, wenn der Impulsstrom in ein spezifiziertes Modell als Sekundärbatteriemodell eingegeben wird, dessen Modellparameterwert durch das Modellparameter-Einstellelement bestimmt wird, konfiguriert ist, eine Modellausgangsspannung als eine Spannungsänderungsform, die von dem spezifizierten Modell ausgegeben wird, zu schätzen, und
   ein Bewertungselement, das konfiguriert ist, basierend auf einem Verhältnis (C/D), bei dem es sich um ein Verhältnis einer Differenz (C) zwischen einem von dem Spannungserkennungselement erkannten Messwert der Spannung der Sekundärbatterie zu einem von dem Spannungseinschätzungselement in jedem ersten Probenahmezeitraum als kurzem Zeitraum geschätzten Schätzergebnis (D) handelt, zu bewerten, ob ein Widerstandswert eines die Zelle konstituierenden Materials der Sekundärbatterie gemäß dem ersten Probenahmezeitraum in einem Referenzbereich liegt oder nicht darin liegt, ob eine Reaktivität einer positiven Elektrode oder einer negativen Elektrode anormal ist oder nicht anormal ist, und, basierend auf einem Verhältnis (C/E), bei dem es sich um das Verhältnis einer Differenz (C) zwischen dem von dem Spannungserkennungselement erkannten Messwert der Spannung der Sekundärbatterie zu einem von dem Spannungseinschätzungselement in jedem zweiten Probenahmezeitraum als langem Zeitraum geschätzten Schätzergebnis (E) handelt, zu bewerten, ob ein Mangel oder eine Verschlechterung einer Elektrolytlösung der Sekundärbatterie gemäß der zweiten Abtastperiode vorliegt oder nicht vorliegt.

2. Vorrichtung zur Überprüfung von Sekundärbatterien gemäß Anspruch 1, wobei das Modellparameter-Einstellelement den Wert des Modellparameters basierend auf jeweils einer Vielzahl von Abtastperioden individuell ermittelt,

   das Spannungseinschätzungselement eine Vielzahl von Modellausgangsspannungen als Spannungsänderungsformen schätzt, die jeweils von einer Vielzahl von spezifizierten Modellen ausgegeben werden, wenn der Impulsstrom in die Vielzahl von spezifizierten Modellen als individuelle Sekundärbatteriemodelle mit den Werten des Modellparameters, die durch das Modellparameter-Einstellelement ermittelt wurden, eingegeben wird, und
   das Bewertungselement eine Vielzahl von Leistungen der Sekundärbatterie jeweils entsprechend der Vielzahl von Probenahmezeiträumen auf Basis des Messergebnisses der Spannung der Sekundärbatterie, das von dem Spannungserkennungselement erkannt wurde, und entsprechend der Vielzahl von spezifizierten Modellausgangsspannungen, die von dem Spannungseinschätzungselement geschätzt wurden, bewertet.

3. Vorrichtung zur Überprüfung von Sekundärbatterien gemäß Anspruch 1 oder Anspruch 2, des Weiteren umfassend:

   ein Temperaturkompensationselement, das ein Messergebnis der Temperatur der Sekundärbatterie erkennt,
   wobei das Modellparameter-Einstellelement den Wert des Modellparameters basierend auf dem Messergebnis der Temperatur der Sekundärbatterie, das von dem Temperaturkompensationselement erkannt wird, korrigiert.

4. Verfahren zur Überprüfung von Sekundärbatterien, das Folgendes umfasst:

   einen Spannungserkennungsvorgang des Erkennens eines Messergebnisses der Spannung einer Sekundärbatterie, wenn ein Impulsstrom in die Sekundärbatterie fließt;
   einen Modellparameter-Einstellungsvorgang des Identifizierens, basierend auf einem Probenahmezeitraum, eines Werts eines Modellparameters eines Sekundärbatteriemodells, bei dem die Impedanz des Innenwiderstands der Sekundärbatterie durch Übertragungsfunktionen ausgedrückt wird, die jeweils ein IIR-System und ein FIR-System darstellen,
   einen Spannungseinschätzvorgang, in dem, wenn der Impulsstrom in ein spezifiziertes Modell als Sekundärbatteriemodell, dessen Modellparameterwert in dem Modellparameter-Einstellvorgang bestimmt wird, eingegeben wird, eine Modellausgangsspannung als eine Spannungsänderungsform, die von dem spezifizierten Modell ausgegeben wird, geschätzt wird, und
   einen Bewertungsvorgang des Bewertens, basierend auf einem Verhältnis (C/D), bei dem es sich um ein

Verhältnis einer Differenz (C) zwischen einem von dem Spannungserkennungselement erkannten Messwert der Spannung der Sekundärbatterie zu einem von dem Spannungseinschätzungselement in jedem ersten Probenahmezeitraum als kurzem Zeitraum geschätzten Schätzergebnis (D) handelt, ob ein Widerstandswert eines die Zelle konstituierenden Materials der Sekundärbatterie gemäß der ersten Abtastperiode in einem Referenzbereich liegt oder nicht darin liegt, ob eine Reaktivität einer positiven Elektrode oder einer negativen Elektrode anormal ist oder nicht anormal ist, und um, basierend auf einem Verhältnis (C/E), bei dem es sich um ein Verhältnis der Differenz (C) zwischen dem von dem Spannungserkennungselement erkannten Messwert der Spannung der Sekundärbatterie zu einem von dem Spannungseinschätzungselement in jedem zweiten Probenahmezeitraum als langem Zeitraum geschätzten Schätzergebnis (E) handelt, zu bewerten, ob ein Mangel oder eine Verschlechterung einer Elektrolytlösung der Sekundärbatterie gemäß der zweiten Abtastperiode vorliegt oder nicht vorliegt.

Revendications

1. Dispositif d'inspection de batterie secondaire comprenant :

un élément de reconnaissance de tension configuré pour reconnaître un résultat de mesure de tension d'une batterie secondaire lorsqu'un courant d'impulsion circule dans la batterie secondaire ;
un élément de réglage de paramètre de modèle configuré pour identifier, sur la base d'une période d'échantillonnage, une valeur d'un paramètre de modèle d'un modèle de batterie secondaire dans lequel une impédance de résistance interne de la batterie secondaire est exprimée par des fonctions de transfert représentant respectivement un système IIR et un système FIR ;
un élément d'estimation de tension qui, lorsque le courant d'impulsion est entré dans un modèle spécifié comme modèle de batterie secondaire duquel la valeur du paramètre de modèle est identifiée par l'élément de réglage de paramètre de modèle, est configuré pour estimer une tension de sortie de modèle comme forme de changement de tension délivrée du modèle spécifié ; et
un élément d'évaluation qui est configuré pour évaluer, sur la base d'un rapport (C/D) qui est un rapport d'une différence (C) d'une valeur mesurée de la tension de la batterie secondaire reconnue par l'élément de reconnaissance de tension sur un résultat d'estimation (D) estimé par l'élément d'estimation de tension dans chaque première période d'échantillonnage comme période courte, si une valeur de résistance d'un matériau constitutif de cellule de la batterie secondaire selon la première période d'échantillonnage est ou non à l'intérieur d'une plage de référence, si une réactivité d'une électrode positive ou d'une électrode négative est ou non anormale, et pour évaluer, sur la base d'un rapport (CIE) qui est un rapport de la différence (C) de la valeur mesurée de la tension de la batterie secondaire reconnue par l'élément de reconnaissance de tension sur un résultat d'estimation (E) estimé par l'élément d'estimation de tension dans chaque deuxième période d'échantillonnage comme période longue, s'il y a ou non une pénurie ou une détérioration d'une solution électrolytique de la batterie secondaire selon la deuxième période d'échantillonnage.

2. Dispositif d'inspection de batterie secondaire selon la revendication 1, dans lequel

l'élément de réglage de paramètre de modèle identifie individuellement la valeur du paramètre de modèle sur la base respectivement de chacune d'une pluralité de périodes d'échantillonnage,
l'élément d'estimation de tension estime une pluralité de tensions de sortie de modèle comme formes de changement de tension respectivement délivrées depuis une pluralité de modèles spécifiés lorsque le courant d'impulsion est entré dans la pluralité de modèles spécifiés comme modèles de batterie secondaire individuels avec les valeurs du paramètre de modèle identifié par l'élément de réglage de paramètre de modèle, et
l'élément d'évaluation évalue une pluralité de performances de la batterie secondaire respectivement selon l'une respective de la pluralité de périodes d'échantillonnage sur la base du résultat de mesure de la tension de la batterie secondaire reconnu par l'élément de reconnaissance de tension et l'une respective de la pluralité de tensions de sortie de modèle spécifié estimées par l'élément d'estimation de tension.

3. Dispositif d'inspection de batterie secondaire selon la revendication 1 ou 2, comprenant en outre

un élément de compensation de température qui reconnaît un résultat de mesure de température de la batterie secondaire,
dans lequel l'élément de réglage de paramètre de modèle corrige la valeur du paramètre de modèle sur la base du résultat de mesure de la température de la batterie secondaire reconnue par l'élément de compensation de

température.

4. Procédé d’inspection de batterie secondaire comprenant :

un processus de reconnaissance de tension consistant à reconnaître un résultat de mesure de tension d’une batterie secondaire lorsqu’un courant d’impulsion circule dans la batterie secondaire ;
un processus de réglage de paramètre de modèle consistant à identifier, sur la base d’une période d’échantillonnage, une valeur d’un paramètre de modèle d’un modèle de batterie secondaire dans lequel une impédance de résistance interne de la batterie secondaire est exprimée par des fonctions de transfert représentant respectivement un système IIR et un système FIR ;
un processus d’estimation de tension dans lequel, lorsque le courant d’impulsion est entré dans un modèle spécifié comme modèle de batterie secondaire duquel la valeur du paramètre de modèle est identifiée dans le processus de réglage de paramètre de modèle, une tension de sortie de modèle comme forme de changement de tension délivrée du modèle spécifié est estimée ; et
un processus d’évaluation consistant à évaluer, sur la base d’un rapport (C/D) qui est un rapport d’une différence (C) d’une valeur mesurée de la tension de la batterie secondaire reconnue par l’élément de reconnaissance de tension sur un résultat d’estimation (D) estimé par l’élément d’estimation de tension dans chaque première période d’échantillonnage comme période courte, si une valeur de résistance d’un matériau constitutif de cellule de la batterie secondaire selon la première période d’échantillonnage est ou non à l’intérieur d’une plage de référence, si une réactivité d’une électrode positive ou d’une électrode négative est ou non anormale, et évaluer, sur la base d’un rapport (C/E) qui est un rapport de la différence (C) de la valeur mesurée de la tension de la batterie secondaire reconnue par l’élément de reconnaissance de tension sur un résultat d’estimation (E) estimé par l’élément d’estimation de tension dans chaque deuxième période d’échantillonnage comme période longue, s’il y a ou non une pénurie ou une détérioration d’une solution électrolytique de la batterie secondaire selon la deuxième période d’échantillonnage.

FIG.1

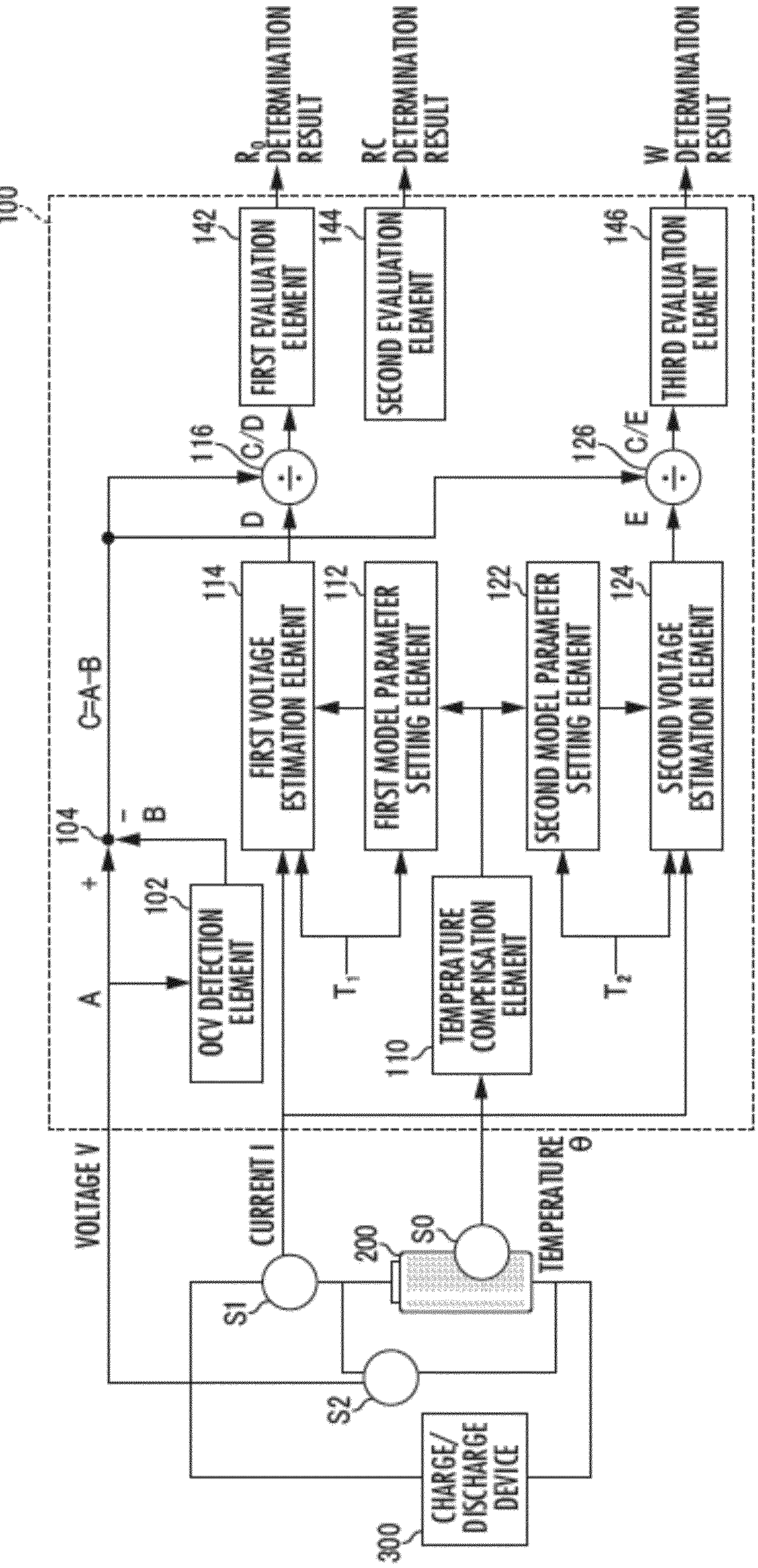

100
VOLTAGE V
CURRENT I
TEMPERATURE θ
A
OCV DETECTION ELEMENT
102
104
+
−
B
C=A−B
110
TEMPERATURE COMPENSATION ELEMENT
T_1
T_2
112
FIRST MODEL PARAMETER SETTING ELEMENT
114
FIRST VOLTAGE ESTIMATION ELEMENT
122
SECOND MODEL PARAMETER SETTING ELEMENT
124
SECOND VOLTAGE ESTIMATION ELEMENT
D
E
116
C/D
126
C/E
142
FIRST EVALUATION ELEMENT
144
SECOND EVALUATION ELEMENT
146
THIRD EVALUATION ELEMENT
R_0 DETERMINATION RESULT
RC DETERMINATION RESULT
W DETERMINATION RESULT
S0
S1
S2
200
TEMPERATURE
300
CHARGE/DISCHARGE DEVICE

FIG.2A

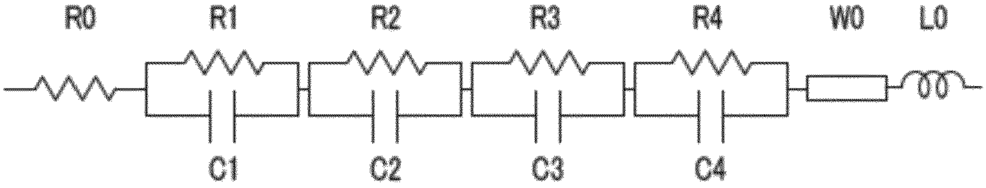


FIG.2B

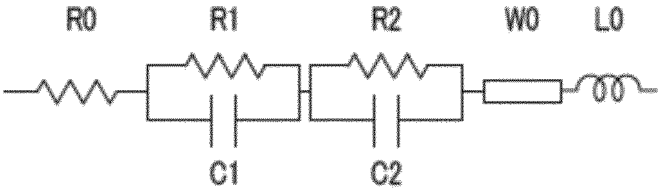


FIG.2C

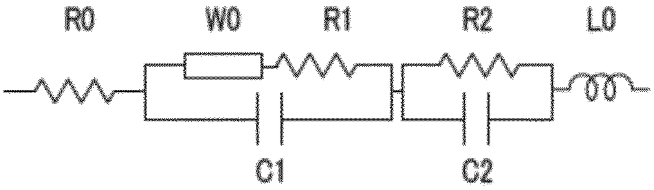


FIG.2D

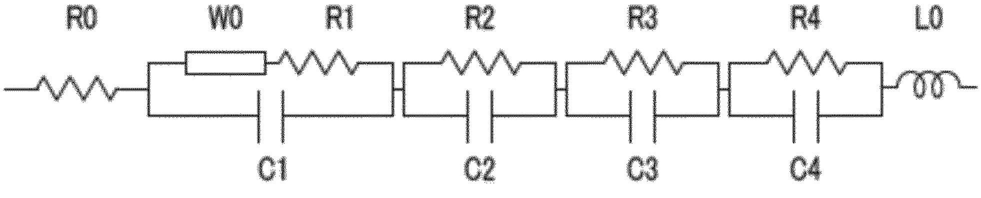


FIG.3A

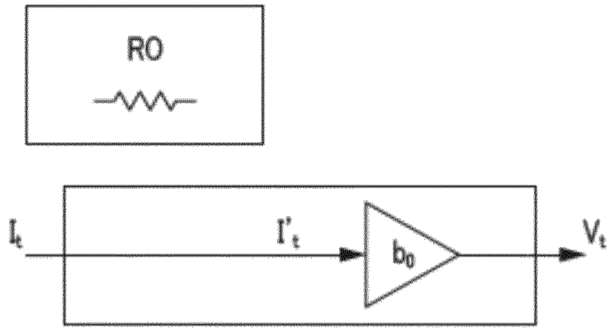


FIG.3B

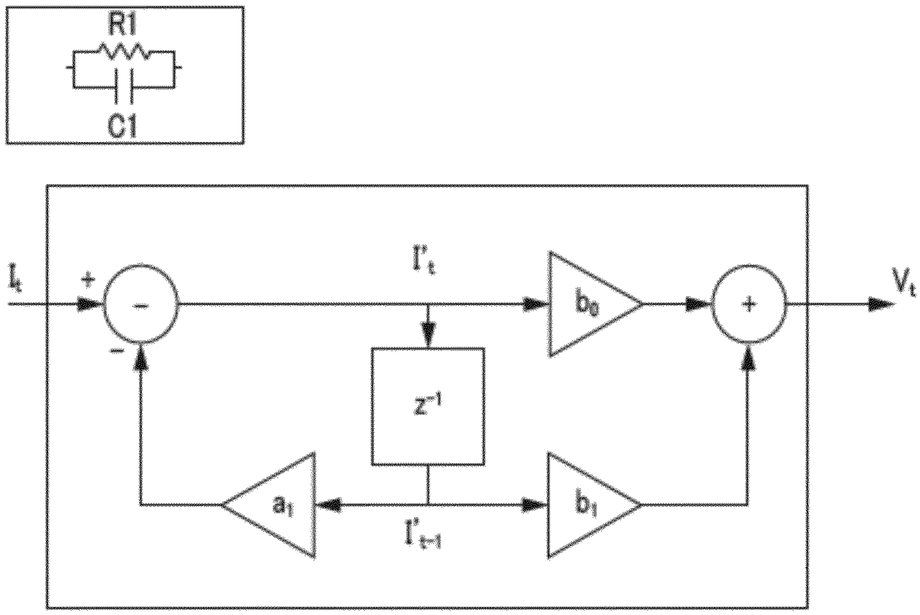


FIG.3C

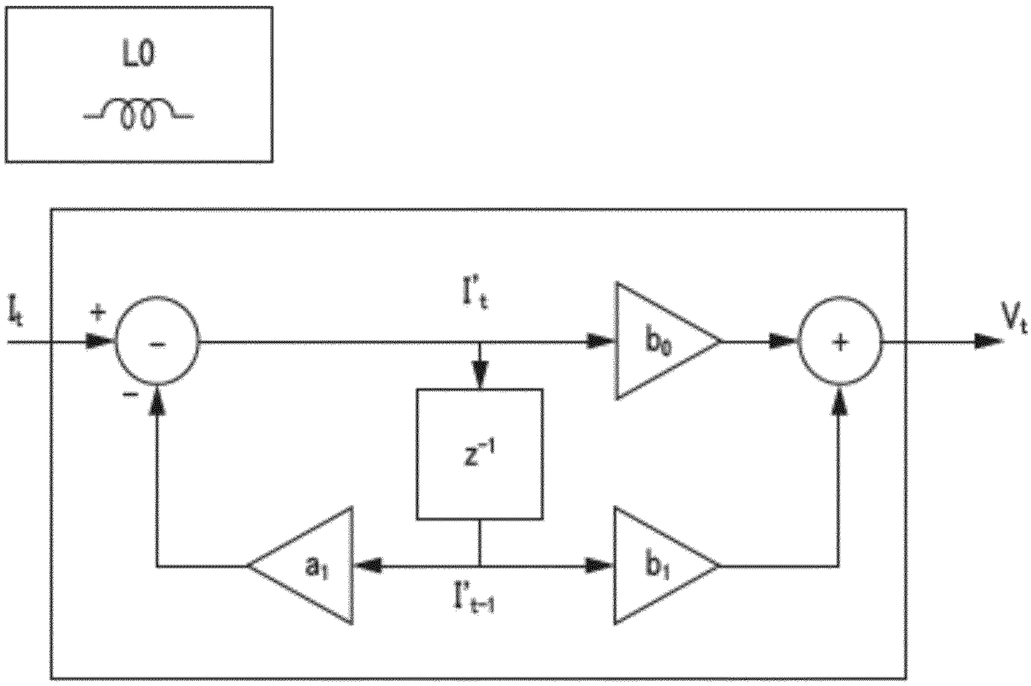


FIG.3D

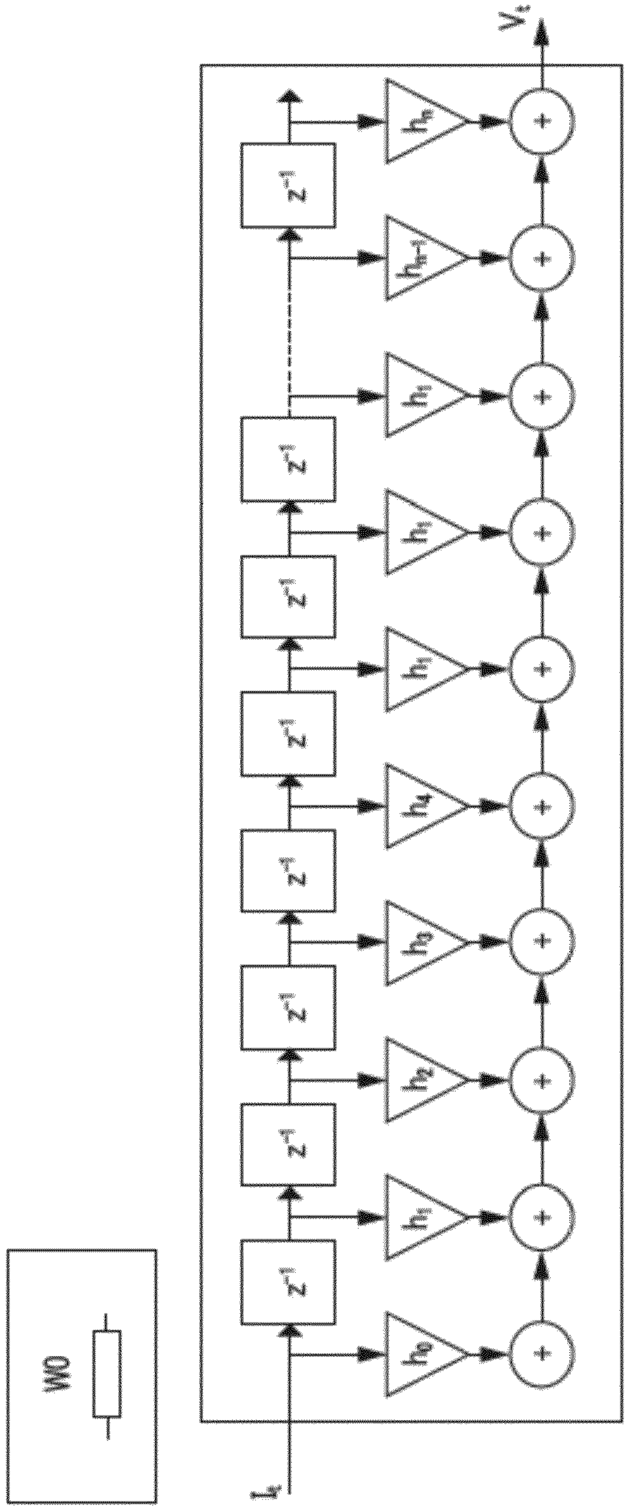


FIG.4

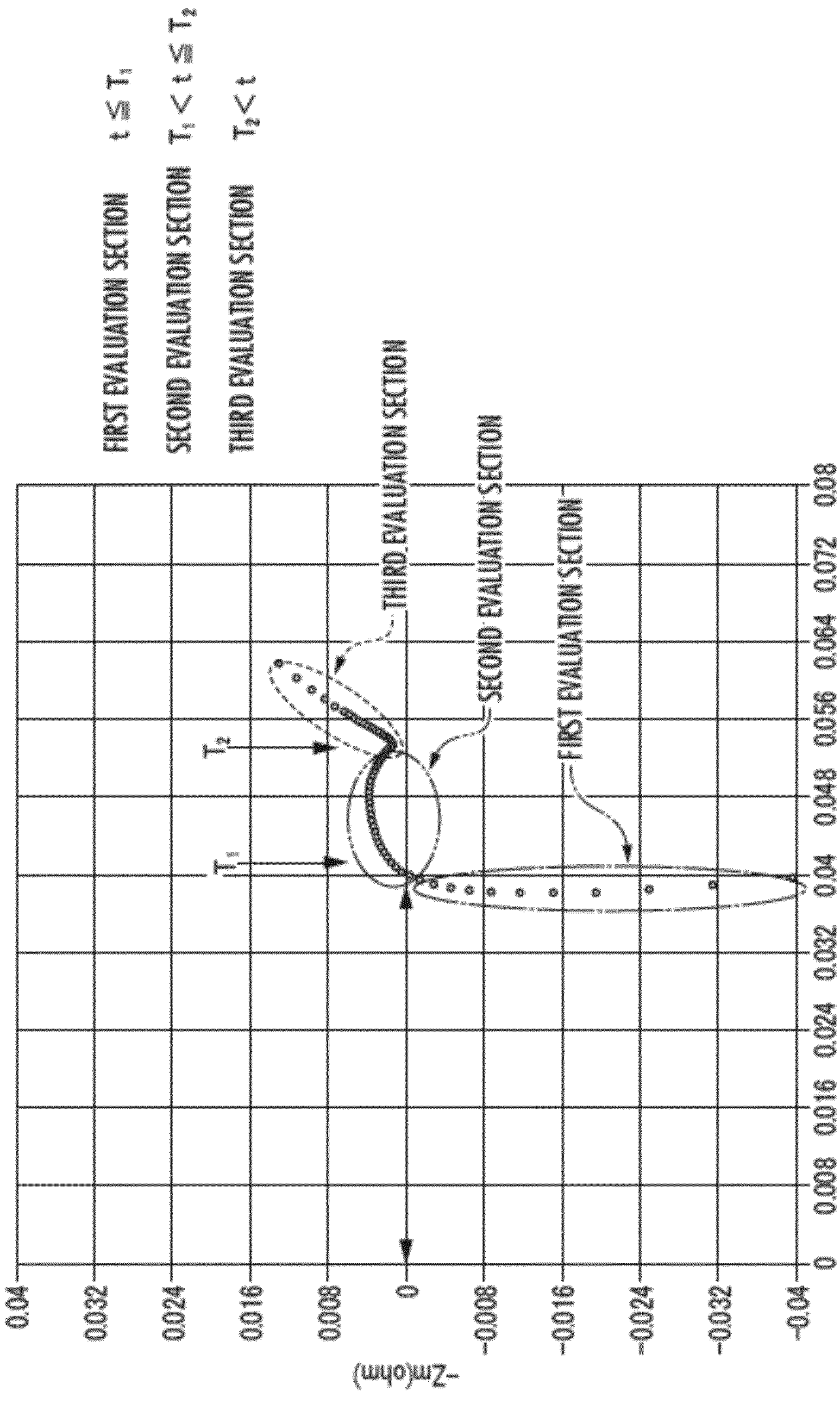

FIRST EVALUATION SECTION $t \leqq T_1$
SECOND EVALUATION SECTION $T_1 < t \leqq T_2$
THIRD EVALUATION SECTION $T_2 < t$
THIRD EVALUATION SECTION
SECOND EVALUATION SECTION
FIRST EVALUATION SECTION
T_2
T_1
-Zm(ohm)
Zre(ohm)
0.04
0.032
0.024
0.016
0.008
0
-0.008
-0.016
-0.024
-0.032
-0.04
0.008
0.016
0.024
0.032
0.04
0.048
0.056
0.064
0.072
0.08

FIG.5A

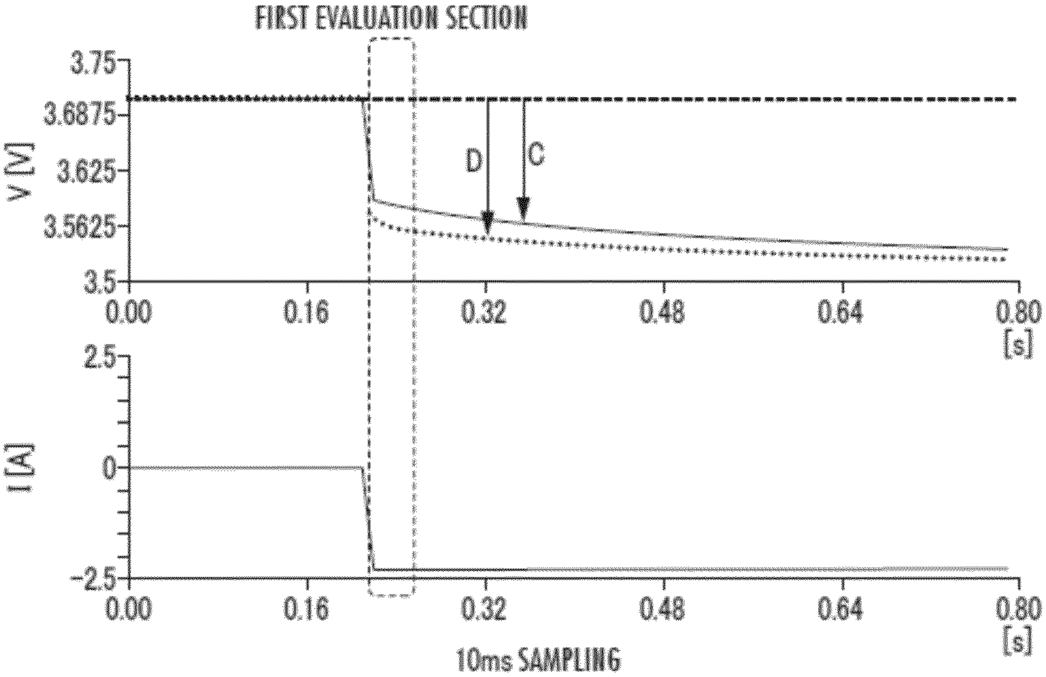
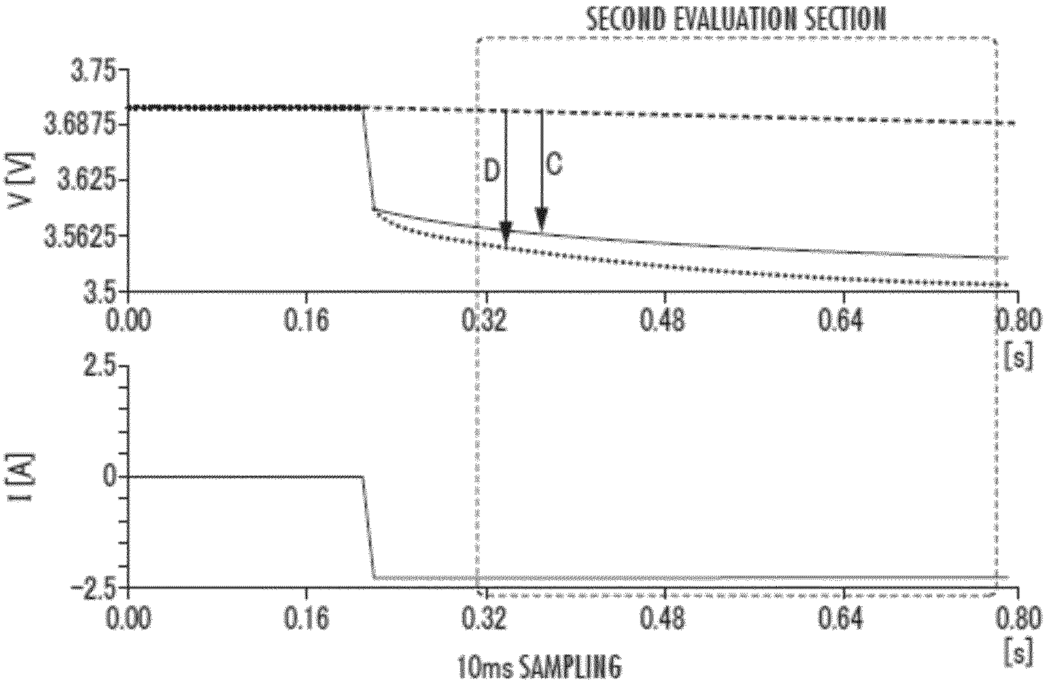

FIRST EVALUATION SECTION
3.75
3.6875
3.625
3.5625
3.5
V [V]
D
C
0.00
0.16
0.32
0.48
0.64
0.80
[s]
2.5
0
-2.5
I [A]
0.00
0.16
0.32
0.48
0.64
0.80
[s]
10ms SAMPLING

FIG.5B


SECOND EVALUATION SECTION
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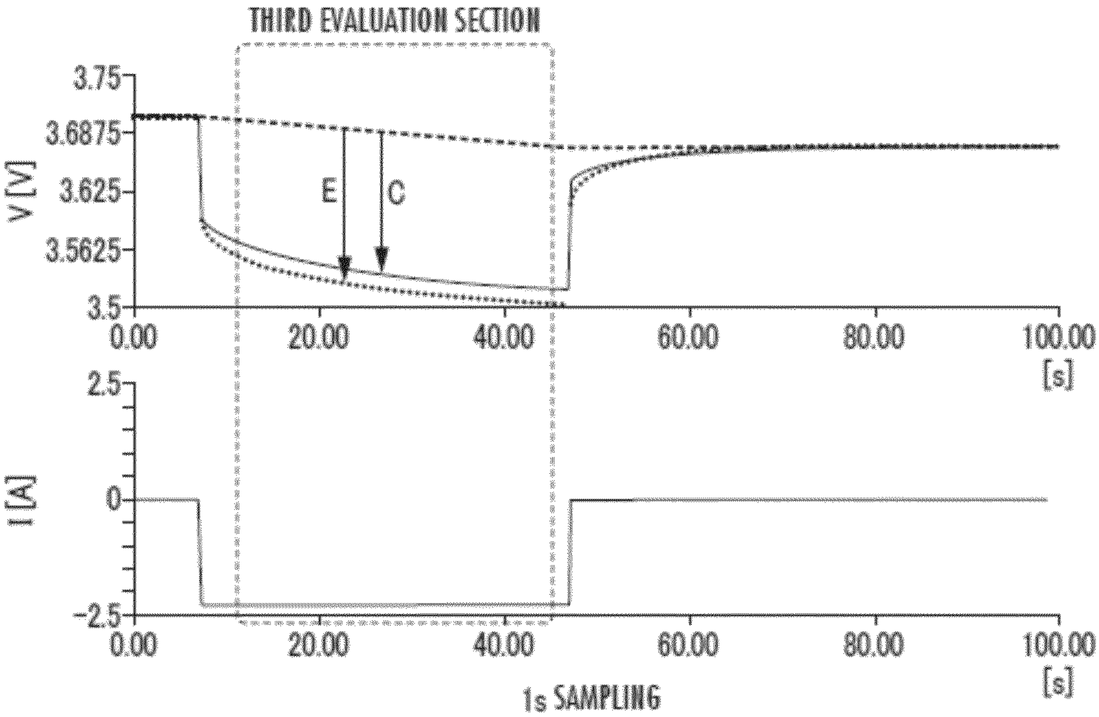
3.625
3.5625
3.5
V [V]
D
C
0.00
0.16
0.32
0.48
0.64
0.80
[s]
2.5
0
-2.5
I [A]
0.00
0.16
0.32
0.48
0.64
0.80
[s]
10ms SAMPLING

FIG.5C


THIRD EVALUATION SECTION
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3.6875
3.625
3.5625
3.5
V [V]
E
C
0.00
20.00
40.00
60.00
80.00
100.00
[s]
2.5
0
-2.5
I [A]
0.00
20.00
40.00
60.00
80.00
100.00
[s]
1s SAMPLING

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 5924617 B **[0004]**
- GB 2532726 A **[0004]**